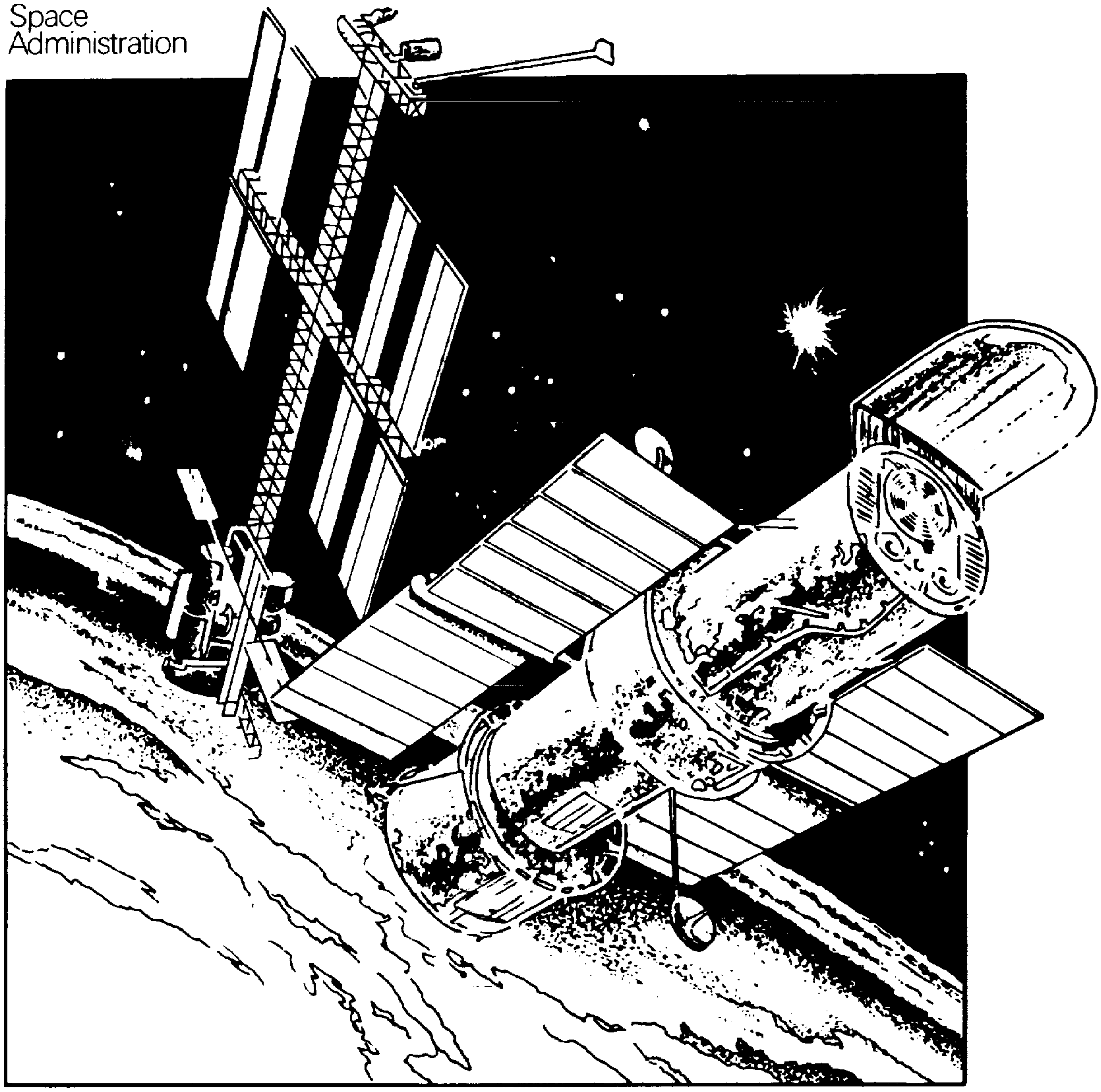
Volume 2
The Space Station
as an Observatory

National
Aeronautics and
Space
Administration



Astrophysics Utilization of the Space Station

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ASTROPHYSICS AND THE SPACE STATION

VOLUME 2

THE SPACE STATION AS AN OBSERVATORY

Intrinsic to the concept of an American Space Station is a spacecraft rich in resources of power, telemetry, structural control, and permanent access to space. It is this richness that makes the Space Station the ideal vehicle for the primary scientific missions of Solar Physics and Cosmic Ray Physics. This volume describes our plan to use the Space Station to grasp the fundamental physics of the Sun with the Advanced Solar Observatory (ASO) and to observe rare but extremely significant components of the cosmic rays with a series of four cosmic-ray experiments.

This volume contains the results of the Panel on the Manned Base as an Observation Platform of the Workshop on Astrophysics Utilization of the Space Station. The panel was composed of solar physicists, cosmic ray physicists, program engineers, and program managers. Its conclusions are developed in three main sections: The Advanced Solar Observatory, Cosmic Ray Experiments, and Technical Requirements. At the very end of the report is a short section on small, attached experiments of opportunity that should be accommodated by the Space Station.

THE ADVANCED SOLAR OBSERVATORY (ASO)

Major Observatory for Solar Physics

The National Academy of Sciences, in its report Astronomy and Astrophysics for the 1980's, recommended the Advanced Solar Observatory as the most important new mission in Solar Physics. Starting with the Solar Optical Telescope and the Pinhole/Occulter Facility, the observatory will be built up from facilities flown on Spacelab, and when the full complement is in place on the Station, we will have an observatory capable of answering the most important and fundamental questions we have about the Sun.

The ASO will be able to overcome the two major limitations of Earth-based observatories. The first limitation is that the Earth's atmosphere allows only that small fraction of the electromagnetic spectrum which we call visible light to reach ground-based telescopes; therefore, many phenomena, especially those of a highly energetic nature, cannot be properly observed because they emit mainly in ultraviolet, extreme ultraviolet, x-ray, or gamma-ray wavelengths that are completely absorbed by Earth's atmosphere. Second, turbulence in the Earth's atmosphere creates an effect known as "seeing" which distorts and smears the smallest features of the Sun's atmosphere and prevents sustained study by diagnostic instruments. Thus, the solar astronomer faces a somewhat ironic situation: although the closeness of the Sun provides copious energy for observation with telescopes and detectors of modest size and sensitivity, nearly all major breakthroughs in modern solar physics are likely to be accomplished only by, or in association with, observations from space.

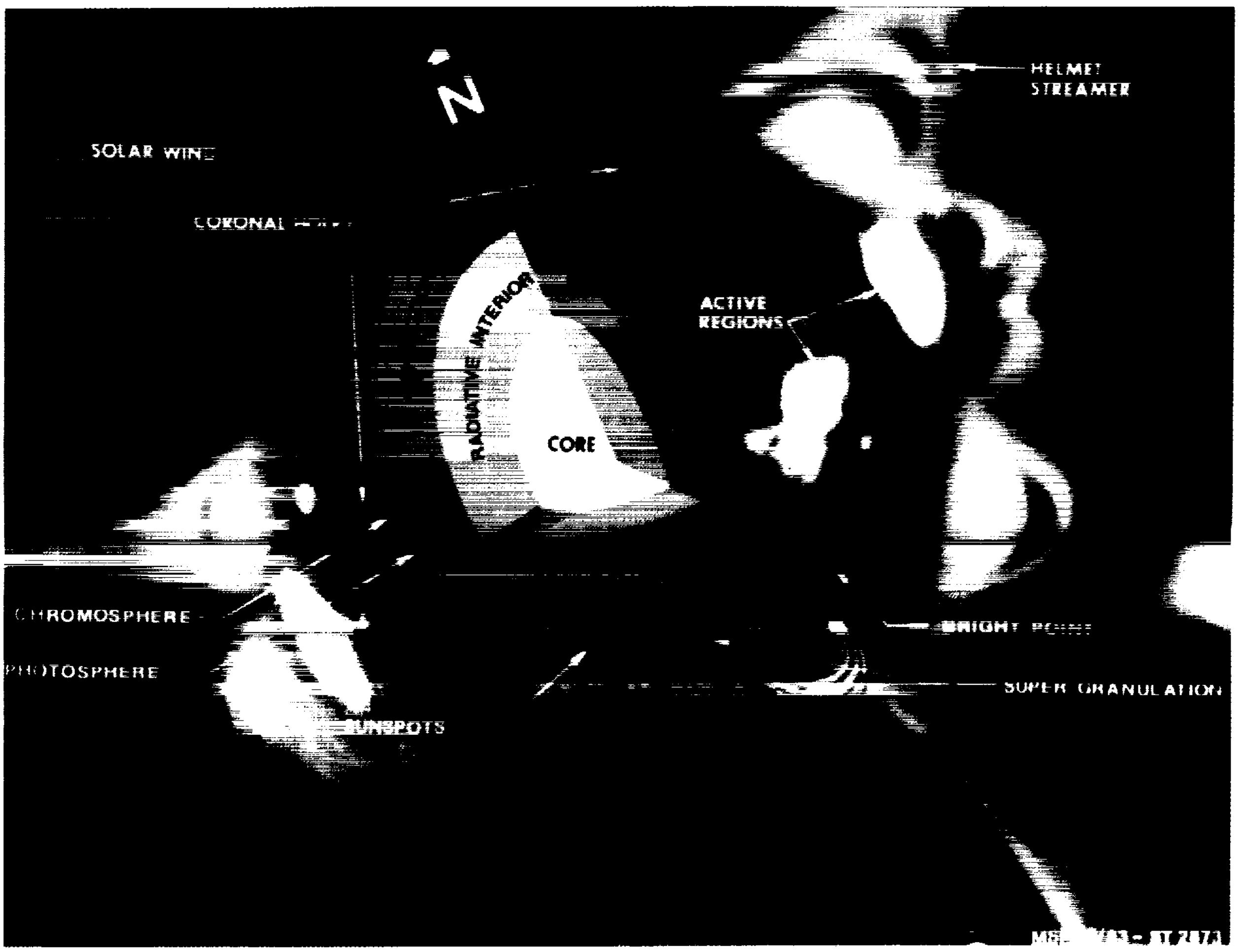

FIGURE 2.1. THE SUN, SHOWING THE MAJOR HELIOGRAPHIC DOMAINS

Heat from nuclear fusion in the core diffuses through the radiative interior and drives the boiling motion of the convection zone. The surface, or photosphere, is at the top of the convection zone, and the boiling can be seen in the network of cells called supergranulation. Convection must also cause--although we do not know how--the strong magnetic regions that occur in sunspots, bright points, active regions, and the structure of the corona. The atmosphere of the Sun consists of a visible inner corona and an invisible outer corona that includes the solar wind. Between the surface and the inner corona lies the chromosphere, which is rich in visible, spectroscopic information.

ASO Suited to Space Station

The Space Station Manned Base is an attractive home for the Advanced Solar Observatory especially because the Station allows ASO to grow from the initial facilities into the major observatory for the Sun covering all wavelengths. The Space Station is unique in having a permanent, manned presence for operations, upgrading instruments, repairing facilities, and replacing consumables. The Skylab experience demonstrated the strong need for close manned monitoring and control of solar telescopes to select the best target areas on the Sun and for quick reaction to capture targets of opportunity. Because of this lesson, solar scientist astronauts (Payload Specialists) will be aboard Spacelab 2 to operate its cluster of solar telescopes.

Because the major ASO instruments will be developed and flown on Spacelab missions prior to long-term deployment on the Space Station, they will be designed to cope with the Shuttle/Spacelab environment. We expect that the Space Station environment will be less severe than that of the Shuttle, particularly for contamination and pointing stability. Hence, the ASO instruments developed on Spacelab will have considerable built-in capability for functioning well on the Space Station.

Solar Physics: Fundamental to Astrophysics

Historically, the study of the Sun has proven to be a Rosetta stone for astrophysics. The Sun first told us that stars can develop strong magnetic fields and that magnetic activity occurs in regular cycles. It was on the Sun that we discovered layers of hot, partially ionized gas called chromospheres that are especially sensitive to the flow of matter and energy from stars, and we discovered atmospheres of fully ionized gas in coronae that are heated (by processes not yet identified) to temperatures more than 1000 times the temperatures of the stars they cover. We learned first from the Sun of cataclysmic releases of radiant and plasma energy and of both sustained and sporadic ejection of matter into interstellar space.

Solar Optical Telescope and High Resolution Telescope Cluster

The High Resolution Telescope Cluster (HRTC) is a group of telescopes that will permit detailed observations of the solar atmosphere over the entire range of temperatures from 5,000 to 10,000,000 K. The instruments in the HRTC, shown in Figure 2.2, include:

- The Solar Optical Telescope (SOT), a high-resolution telescope sensitive from the infrared, through visible and into vacuum ultraviolet wavelengths.

- The Soft X-Ray Telescope, sensitive to low energy ("soft") x-rays, which will allow detailed observations of the behavior of the Sun's corona (where the temperature is between 1 million and 5 million degrees).

- The EUV Telescope, sensitive to extreme ultraviolet (EUV) rays, which will obtain information about the chromosphere/corona transition region (where the temperature ranges from 500,000 to 10 million degrees).

These instruments can work either independently or together. When working together, they will be able to study the constantly changing phenomena that determine the structure and dynamics of the chromosphere and corona through the full range of temperatures now known to be involved in many solar phenomena.

The HRTC will also study the sudden release of energy and high energy particles that accompanies a solar flare. In a flare, both the buildup and the release of energy appear to depend critically on the fine structure of the solar magnetic field, which is reflected in the fine details observed at all temperatures in the solar atmosphere.

The first of these telescopes, the Solar Optical Telescope, is already being developed and will be used on Spacelab in the early 1990's. Because the Solar Optical Telescope will be used first, it is the only one that is discussed in detail in this volume. However, some of the instrumentation supporting the HRTC is also discussed, particularly the helioseismometer.

The Solar Optical Telescope

The most demanding of all the ASO facilities will also be the first one developed. The SOT will investigate the fundamental physics of the surface atmospheres of the Sun, as shown in Figure 2.3.

The SOT is a 1.25-meter telescope achieving 0.1 arcsecond (about 100 kilometer) resolution over the ultraviolet, visible, and infrared spectrum from 1100 to 10,000 Angstroms. The optical configuration is Gregorian, in which the secondary mirror is concave and placed beyond the image formed by the primary mirror. This allows a reflective stop to be placed right at the primary focus to divert most of the light and heat away from the secondary mirror, except for the light from the relatively small area under study, which passes through a hole in this heat rejection mirror. The secondary and tertiary mirrors focus this light into the scientific instruments. With this optical system, and by careful control of contamination, the SOT's design should provide excellent performance in the vacuum ultraviolet.

The science instruments that will accompany the SOT on its first Spacelab mission include two film cameras, a visible light filtergraph-polarimeter, and visible and ultraviolet spectrometers.

The telescope housing also supports the focal plane instruments, and the entire ensemble is mounted on Spacelab's Instrument Pointing System. During the course of its development flights on the Space Shuttle, the SOT will carry the other HRTC instruments as well.

Helioseismometer

Current technology will not allow high resolution over the entire face of the Sun; high resolution instruments are necessarily limited to narrow fields of view. There are, however, important observations to be made over the Sun as a whole. These include wide field x-ray and extreme ultraviolet views of the Sun and its lower atmosphere. A gamma ray and neutron spectrometer will be included in the HRTC to study the acceleration of electrons and ions to very high energies, providing information about the Sun as a whole. But one of the most specialized instruments supporting the HRTC is the helioseismometer, which will be able to study the Sun's interior.

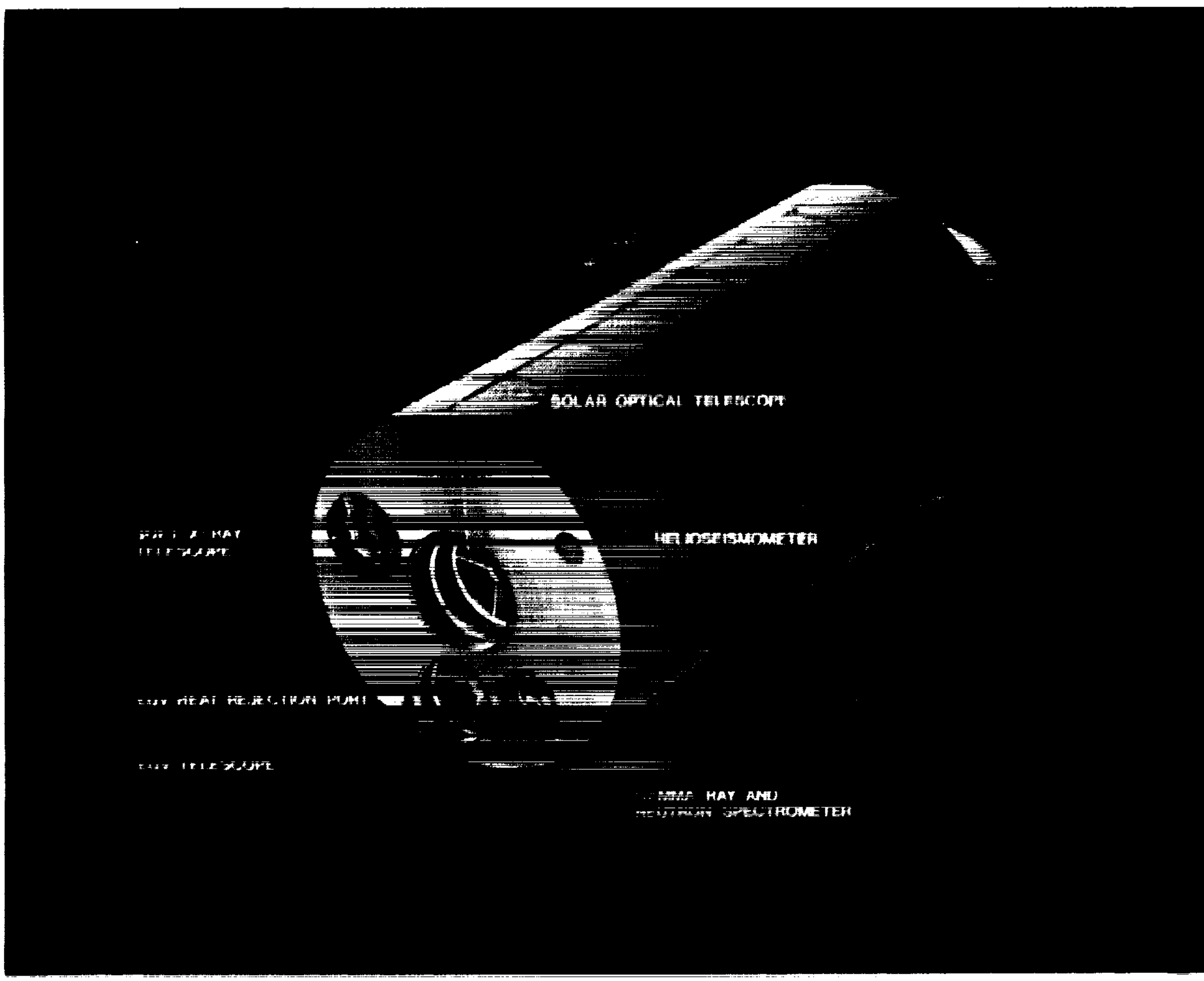

FIGURE 2.2. THE SOLAR OPTICAL TELESCOPE AND THE HIGH RESOLUTION TELESCOPE CLUSTER

The primary high resolution instruments--the SOT, the Soft X-Ray Telescope Facility, and the Extreme Ultraviolet (EUV) Telescope Facility--are accompanied by wide-field instruments such as the Gamma Ray and Neutron Spectrometer and the Helioseismometer shown here. Other wide-field and high resolution instruments will be added during the ASO mission on the Space Station.

The helioseismometer is a modest-sized, 12-centimeter visible light telescope. However, it will perform what in some ways will be the most profound observations of the entire ASO: recording the subtle vibrations of the Sun to find out what is going on far below the visible surface.

The fact that the Sun's interior can be studied at all by observing its outer surface is a relatively new development in solar physics. The helioseismometer will measure oscillations on the Sun's surface and relate them to the Sun's internal structure, just as earthquakes are used to infer the subsurface structure of the Earth. The key to using this technique successfully is to measure the speed (meters, or even centimeters, per second) of small portions of the Sun's surface for a long time (weeks to months).

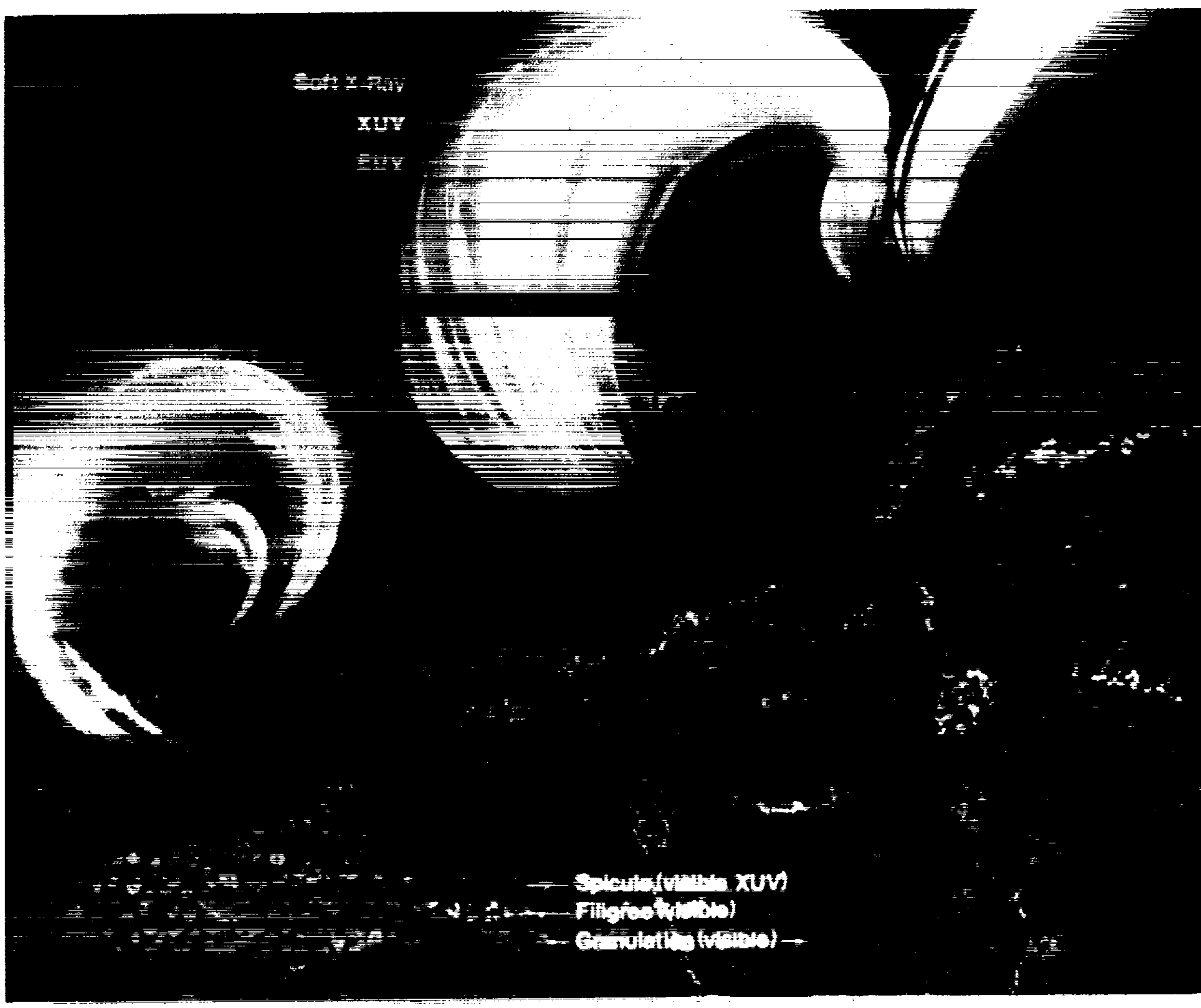

FIGURE 2.3. FUNDAMENTAL PHYSICS OF THE SURFACE OF THE SUN

When we observe the Sun in visible light, the smallest structures we can resolve are granulation, spicules, and filigree. With the Solar Optical Telescope, we will be able to resolve much smaller structures--as little as 100 kilometers across. With this improved resolution, we expect a leap in understanding comparable to that which occurred when microscopes first resolved living cells.

Such long periods of uninterrupted observation are only obtainable in space. The view from space can also reliably provide clues to the source of the Sun's magnetic field. This fact makes the helioseismometer one of the most interesting of the instruments supporting the HRTC.

Pinhole/Occulter Facility

Although the Pinhole/Occulter Facility (P/OF) may be the second major facility developed for the ASO, it may be the first to fly on the Space Station, since its planned development schedule coincides with that of the Space Station.

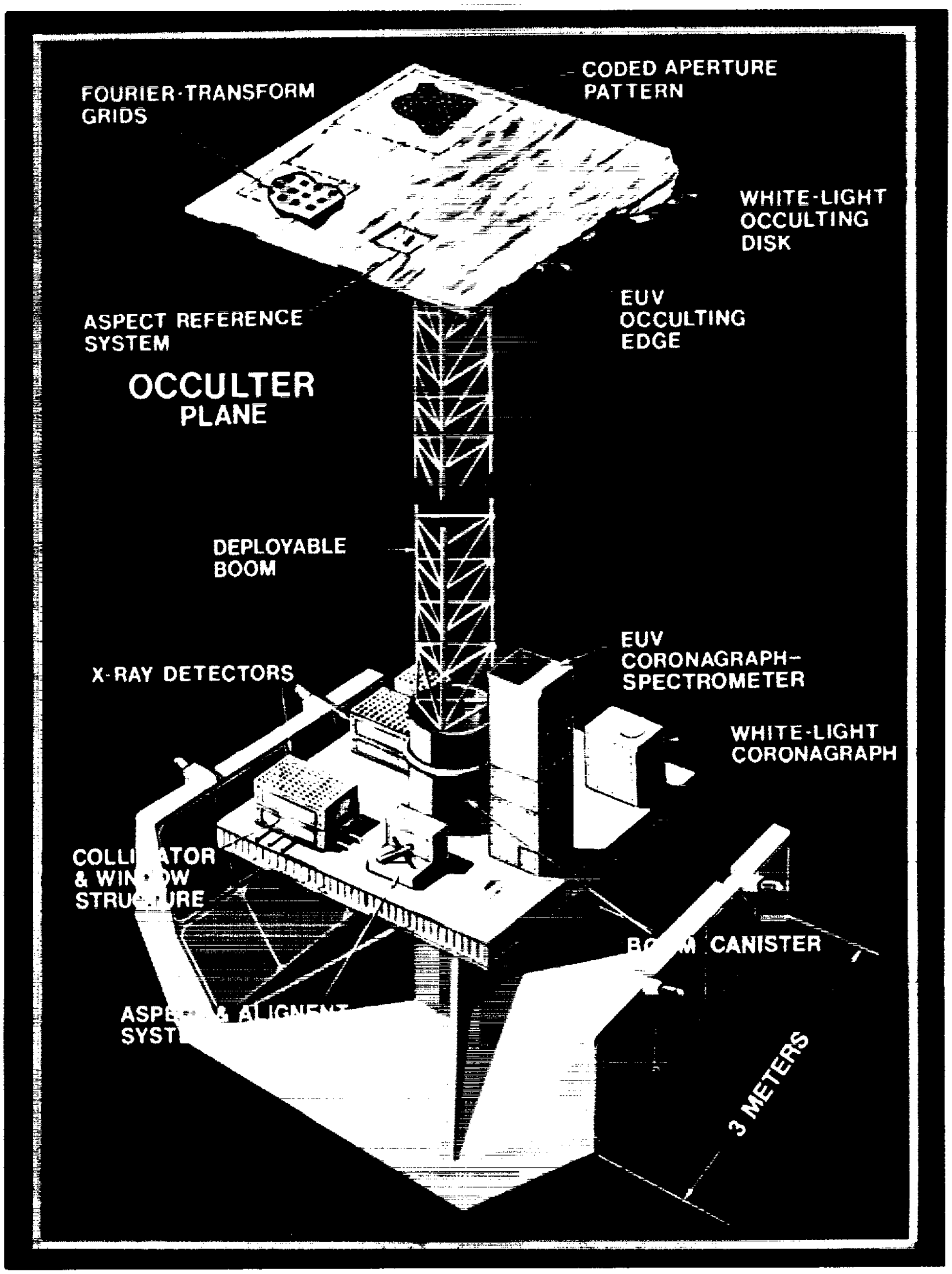

FIGURE 2.4. PINHOLE/OCCULTER FACILITY

While physically large, the P/OF is deceptively simple. Figure 2.4 shows the P/OF with its 50-meter boom separating the instruments from a combined occulting edge and pinhole mask. The occulting edge acts as an artificial moon to create an "eclipse" for instruments viewing the Sun's corona, while the pinhole mask lets x-rays from solar flares through its small holes onto an array of x-ray detectors. The extremely long boom is critical both for providing an optimum "eclipse" geometry as well as achieving high angular resolution of the x-ray imaging. Imaging through a pinhole is the simplest camera possible; by taking this approach, the P/OF is able to produce images with "hard" x-rays whose energies are too high to be reflected by grazing incidence telescopes such as the Soft X-Ray Telescope in the High-Resolution Telescope Cluster. The occulter of the P/OF produces a good reproduction of an eclipse so that instruments can observe the faint outer atmospheres of the Sun, its chromosphere and corona, without the overpowering glare from the disk.

The impetus for coronal observations with the P/OF comes from two major developments in the 1970's. First, the study of the Sun's inner corona without the benefit of a natural eclipse was vaulted into the space age by the successful operation of white light coronagraphs and soft x-ray telescopes on OSO-7 and Skylab in the mid-1970's (Figure 2.5). The second major advance, also in the middle 1970's, came with the finding that certain coronal emissions, first observed in a rocket-borne experiment during the solar eclipse of 1970, could directly measure the velocities and temperatures of ions in the coronal plasma.

As a result of these developments, once the P/OF is in space, we will be able to discover the fundamental plasma parameters--temperature, density, and velocity--entirely by remote optical techniques. Coronal white light will be used to measure the density of electrons, and coronal ultraviolet light will be used to measure the temperature of the electrons, the state of ionization for atoms heavier than hydrogen, and the velocity and temperature of hydrogen ions. Thus the P/OF will be able to tell us practically everything that we need to know in order to infer how the Sun's corona is heated to the point where it finally escapes as the solar wind.

The Advanced Solar Observatory and the Solar Terrestrial Observatory

When we learn about the physical nature of the Sun, we not only learn fundamental science but also obtain practical information that one day may allow us to predict conditions on Earth that are affected by conditions on the Sun. The Sun's ultraviolet light, x-rays, and solar wind cause events in the earth's magnetosphere such as geomagnetic storms, short wave radio fadeout and aurorae. As technology in our lives becomes more sophisticated and more sensitive, we become increasingly affected by these phenomena.

One mission that has been proposed specifically to understand the possible effects of solar variability on the Earth's atmosphere is the

Solar-Terrestrial Observatory (STO). An obvious criterion for a successful study of solar-terrestrial relationships is that of long term observations--ideally a full solar cycle of 11 years. The Space Station can be an essential base for such a program.

FIGURE 2.5. LARGE CORONAL EJECTION OBSERVED WITH THE CORONAGRAPH ON SKYLAB

The occulting disk covers twice the diameter of the Sun.

The STO, as currently envisioned, has four main groupings of instruments: the first will optically monitor solar activity and measure total luminosity and the irradiance in specific spectral bands; the second will measure the solar wind flux just outside the Earth's magnetosphere; the third will measure mass and energy transport through the magnetosphere and into the Earth's ionosphere; and the fourth will monitor by remote optical techniques the electric currents, photochemical processes, atmospheric turbidity, and other responses of the lower terrestrial atmosphere. Altogether, a fully implemented STO could involve 20 to 40 separate instruments.

The functions of some of the STO's solar instruments can be accomplished by those planned for the fully mature ASO on the Space Station. The solar wind measurements would, of course, have to be made in interplanetary space. The other two parts of the STO payload would be accomplished by a mix of in situ spacecraft and instruments located on the Space Station; in either case they would be available for periodic refurbishment and servicing using the capability of the Space Station.

COSMIC RAY EXPERIMENTS

Because of its resources in size, human access, and long duration in space, the Space Station is ideal for conducting cosmic ray experiments to observe the most energetic particles known to exist. These experiments will investigate the physics of particles traveling at very close to the speed of light, and they will reveal where cosmic rays come from, what it was like where they were accelerated, and what they traveled through to reach Earth. These are the fundamental problems of cosmic ray physics.

Unlike electromagnetic radiation, cosmic rays are charged particles. Most are the nuclei of normal atoms that have been stripped of their electrons and accelerated to more than 99 percent of the speed of light. Some carry more than 1 Joule of energy in a single proton. There are also electrons among the cosmic rays, and although electrons are less than 1 percent of the total, they are just as energetic.

The big question remains: How did the cosmic rays receive their enormous energies? In 1979, we were fairly certain that cosmic rays were accelerated in supernova explosions, and in that year, we launched the Third High Energy Astronomy Observatory (HEAO-3) to find the heavy cosmic ray nuclei like uranium that can only be created explosively. We expected to learn a lot about the nuclear events occurring at the onset of a supernova, but by the middle of 1980, it was already clear that the theory was wrong. Although supernova explosions may supply the energy to accelerate the cosmic rays, they do not do it directly, and they do not supply the particles themselves. We are still left with the big question.

The Space Station is a unique and ideal platform from which to answer that question. Because cosmic rays are charged, they generally must bend around magnetic field lines. However, at velocities very close to the speed of light, they can penetrate the Earth's magnetic field with little bending. In near-Earth orbit, the Space Station will carry instruments with wide fields of view, to maximize the number of particles that can observed.

The Space Station also provides opportunities for long-term observations and the capability for in-space construction. These are necessary to obtain the collecting power required to study large numbers of these extremely energetic particles.

The following summarizes a plan for using the Space Station to support three major cosmic ray experiments: the Cosmic Ray Nuclei Experiment/Transition Radiation and Ionization Calorimeter (CRNE/TRIC) to determine what cosmic rays have traveled through to reach the Earth; the High Energy Space Station Array (HESS Array) to determine how the cosmic rays were accelerated and how atomic nuclei behave; and the Superconducting Magnet Facility (SCMF) to determine why cosmic rays remain in our galaxy. A fourth experiment, the High-Energy Isotope Experiment (HEIE), is described here to show how the set of four experiments can work together to solve intertwined problems of the synthesis of cosmic ray nuclei, their acceleration, their transport through the gas of the interstellar medium, and their escape from the galaxy. Each of these experimental packages will evolve through the Spacelab or Shuttle-Attached-Payloads programs.

Cosmic Ray Nuclei Experiment/Transition Radiation and Ionization Calorimeter

The Transition Radiation and Ionization Calorimeter (TRIC) will be a reconfiguration of the Cosmic Ray Nuclei Experiment (CRNE) developed for Spacelab 2. In addition to the transition radiation detectors of the CRNE, the TRIC package will include an ionization calorimeter to measure the total energy of incoming cosmic rays. CRNE/TRIC will fit inside the pressurized shell shown in Figure 2.6 and will have essentially the same electrical and mechanical interfaces as the CRNE Spacelab experiment. After 2 years of operation on the Space Station, CRNE/TRIC will have measured the energies of protons and helium nuclei with energies up to a million GeV and the energies of rarer nuclei (up to zinc in the periodic table) with energies up to at least 1000 GeV and perhaps even to 10,000 GeV. We use the GeV (giga electron-volt) as a convenient unit of energy for cosmic rays; if all the mass in a proton or neutron were converted to energy, the energy, mc^2, would equal 0.94 GeV.

Transport

Imagine what the Galaxy looks like to a cosmic ray. From the point of view of a primary cosmic ray--an oxygen nucleus, for example--traveling at a speed that differs from the speed of light by only one part in a million, the magnetic field of the Galaxy will appear as a rotating electric field that moves the nucleus in a circle as the Galaxy rushes by. Meanwhile, the stars and all the gas and dust between the stars appear to crowd together into a bunch racing directly toward the nucleus.

The stars are easy to miss; there are few of them. But the gas particles are there by the billions, each atom approaching at velocities not yet achieved in the most energetic particle accelerator on Earth. Within a few thousand years, from the point of view of the nucleus, either the Galaxy will pass by, or one of those extremely energetic atoms will strike it, blasting the nucleus backwards into a shower of nuclear fragments called secondary cosmic rays.

FIGURE 2.6. THE COSMIC RAY NUCLEI EXPERIMENT FOR SPACELAB 2

This experiment will operate from the Space Shuttle bay to investigate the composition of cosmic rays with energies between 20 GeV and 1000 GeV. Its complex interior design will be modified to create the Transition Radiation and Ionization Calorimeter experiment for the Space Station. The external design and the interfaces will not be changed.

TRIC to Solve the Transport Problem

The problem is to separate the secondary cosmic rays from the primary ones. The primary composition will tell us the composition of the source of the cosmic rays, and analysis of the secondaries will tell us about the matter that the primaries have traveled through to reach the Earth. By being tuned to the highest energies that can yield a significant statistical sample, CRNE/TRIC will be ideal for analyzing the transport of cosmic rays and determining the composition at the source.

CRNE/TRIC can easily tell which of the cosmic rays it sees are the secondary nuclear fragments of more massive primary cosmic rays. Lithium is an example. Lithium is relatively plentiful among the cosmic rays (although hydrogen and helium are much more abundant), but it is extremely rare within the solar system. Clearly, the cosmic ray lithium comes from the collisions of abundant carbon, nitrogen, and oxygen cosmic rays with the gas between the stars.

Proof comes from the fact that lithium gets rarer at higher energies more quickly than the carbon, nitrogen, or oxygen from which it comes. In general, the energetic primaries that produce energetic secondaries suffer a greater shock than less energetic primaries when they collide with the interstellar gas. As a result, secondaries become much less important at higher energies.

This makes CRNE/TRIC ideal for distinguishing between primary and secondary contributions to cosmic rays where the distinction is not so clear as it is for lithium. At the highest energies, the primary cosmic ray contribution should dominate and provide an unambiguous measurement of the composition at the source.

Sample of Material from Beyond the Solar System

The solar system material was assembled out of interstellar gas and dust 4.6 billion years ago, while the cosmic ray material is only about 10 million years old--based on radioactive dating. Already, from HEAO-3 and balloon-borne cosmic ray experiments, we have discovered small but significant differences between solar system abundances and cosmic ray abundances.

The most provocative difference is an overall trend with a small excess of atoms that are easy to ionize and a slight deficiency of atoms that are hard to ionize. Acceleration cannot proceed while the atoms are electrically neutral, so this dependence on ionization threshold could be very significant. If cosmic rays are formed in explosive events, such as a supernova, then all atoms would be ionized no matter what their threshold. However, if the initial accelerations occurred in a more gentle, low-temperature region, the atoms would be selectively ionized. What we have seen suggests that the initial acceleration occurred in gas that was between 10,000 and 15,000 degrees--the temperature characteristic of gas surrounding young, hot stars.

Superconducting Magnet Facility

The Superconducting Magnet Facility (SCMF) will use a powerful superconducting magnet on the Space Station to investigate four significant aspects of the cosmic ray puzzle that cannot be observed any other way. Magnetic spectrometers are unique in their ability to determine the charge of a particle. This capability will allow us to look for antimatter--antiprotons, positrons, and heavier antinuclei such as antihelium.

The significance of antiprotons and positrons is that we know their rate of production, so SCMF will be able to teach us about the rate at which they are lost. SCMF will also resolve an enigma in low-energy antiprotons: the unexplained excess of low-energy antiprotons in cosmic rays. More profound would be the discovery of an antinucleus other than an antiproton. Antihelium, for example, could never be produced as a secondary particle from the collision of two normal nuclei; it could only appear in our detectors if it were a primary cosmic ray--that is, if it came from a region of space composed of antimatter stars and galaxies.

To deflect these particles, SCMF will need to produce a magnetic field that is more than a thousand times the strength of the Earth's magnetic field. Furthermore, this field must be nearly uniform over a wide area, about 1 square meter. Such a field is really only conceivable with electromagnets, and the only reasonable approach in space is to use a superconducting electromagnet, which is made with wires that have exactly zero resistance when they are cooled to the temperature of liquid helium. Once a superconducting magnet is charged, no additional power is required to keep it going.

Besides giving support to the SCMF and a clear view of space, the Space Station is especially attractive because it provides a means of resupplying the liquid helium that keeps the magnet superconducting. This would be required every 6 to 12 months, depending on the design.

The presence of people on the Space Station will allow the SCMF to be rearranged to accommodate a wide variety of experiments. In addition to the antimatter searches, these include studies of cosmic ray isotopic composition, radioactive nuclei, accurate determination of elemental energy spectra, electron spectra, and possibly nuclear interaction studies with "tagged" heavy nuclei. When built, the SCMF will be the focus of cosmic ray studies through the end of the century.

High-Energy Isotope Experiment

HEIE is another important cosmic ray experiment that can be carried out with the volume, weight, power, and telemetry requirements of CRNE/TRIC. Unlike those missions, however, the HEIE will only gather useful data when it is at latitudes greater than about 45 degrees. Only there will the instrument have access to cosmic rays with energies low enough to measure their masses along with their charges and energies.

Ideally, we would like to know the mass of each cosmic ray that reaches any of our experiments--in addition to knowing the cosmic ray's charge and energy. Although a general description of a nucleus is contained in its charge (the number of protons it has), its specific nuclear history is often encoded in the number of neutrons it has. This is revealed by measuring the mass.

Observations made at high latitudes by balloon-borne experiments have found that cosmic-ray neon, magnesium, and silicon contain more neutron-rich isotopes than the same terrestrial elements, but this is very difficult to understand with our current theories of how nuclei are formed.

High-Energy Space Station Array

The High-Energy Space Station Array (HESS Array) is made possible by the technical capability provided by the Space Station to assemble large facilities in space. The Space Station will allow us to assemble the HESS Array and operate it for the 2 years necessary to find out how the acceleration of a cosmic ray depends on its composition at the highest energies.

Deployed in space, the HESS Array will be able to determine the compositions of cosmic rays that cause showers of particles in the Earth's atmosphere. This is a fundamental observation in cosmic-ray studies, and it affects a wide variety of Earth-based observations. The detector must be able to identify the charge and measure the energy of a cosmic ray with an energy of several million GeV; these cosmic rays are exceedingly rare, so the detector must be very large (about 4 meters on a side) just to observe enough cosmic rays in 2 years to tell how the composition of the showers changes with energy. Consequently, the HESS Array will be so massive that it cannot be carried up in a single Shuttle launch; it will have to be carried up in pieces and put together in orbit. This will be possible only with a manned Space Station.

In addition to providing information about the cosmic rays themselves, the HESS Array will provide physicists with a unique probe of the atomic nucleus. The HESS Array will contain space for nuclear target and track-recording materials that will be removed every 3 months and sent back to the Earth for analysis. Investigators from around the world will provide target materials and analyze the exposed materials.

The cosmic rays will collide with the targets at a velocity so close to the speed of light that the collision products should be solely the result of strong nuclear interactions, the most enigmatic forces known to science.

TECHNICAL REQUIREMENTS

The following discussion outlines technical requirements for accommodating the Advanced Solar Observatory and the cosmic ray experiments on the Space Station.

Advanced Solar Observatory (ASO)

The ASO is a dynamic system that will evolve with time, perhaps starting with P/OF, and then adding the SOT and the HRTC. Therefore, the first requirement is that the ASO Study Manager work with the Space Station systems engineers to define the interface between ASO and the Station.

The mass requirements cited for ASO refer to the instruments only and do not include supporting systems such as pointing mounts, platforms, and cabling. The pointing requirements refer to the High-Resolution Telescope Cluster as a unit and do not include the next higher level of control to be provided by internal image-motion compensation, which takes the instruments to their ultimate performance. The fundamental pointing requirement is to have a clear view of the Sun during all sunlit portions of the orbit. The data rates specified refer to that after data compression (which could be a factor of five) and for periods requiring maximum resolution (e.g., solar flares). The command rate is included to indicate the case in which the ASO is commanded from the ground; this will be the primary backup mode of operation. Electrical power is for the normal operations of all the Advanced Solar Observatory instruments. The temperature range is determined by the electronics requirements and by the need to avoid surface condensation. It should be noted that the ASO instruments will be especially sensitive to various types of contaminants, including hydrocarbons, particulates, and radiation.

To provide optimum operational interaction, a command and control console will be required inside the pressurized ASO module. This console will consist of (at a minimum) power panels for each of the ASO instruments; video and digital displays; controllers for the pointing mounts and instrument protective doors; controls for P/OF boom deployment and retraction; and at least two keyboards for controlling the instruments when necessary. The Space Station crew will be involved in the daily routine operations of the ASO, with additional personnel being required when intensive, nonroutine operations are carried out. Servicing and maintenance of the telescopes and instruments will be required periodically, and the crew will be required to make changes in focal plane instruments and to replace or upgrade other instruments.

Pinhole/Occulter Facility (P/OF)

Mass - 3,000 kg
Data rate - 1.4 Mbps
Command rate - 1.0 kbps
Internal volume - 3.0 m^3
Power to P/OF instruments - 0.500 kW
Power to the internal volume - 70 W

Solar Optical Telescope (SOT)

The most useful general statement one can make about the requirements which the SOT will impose on the Space Station is that the requirements for pointing accuracy and stability, command and control capability, data telemetry rate, and contamination control which the SOT imposes on the Shuttle also will have to be met by the Space Station. The requirements of the SOT, though less in some quantities than the total requirements of the HRTC, are representative of the requirements of the HRTC.

Mass - 4000 kg
Power across gimbal* - 5.0 kW
Pointing accuracy* - 2 arcsec
Pointing stability* - 0.1 arcsec
Data telemetry rate - 8 Mbps
Command rate - 2 kbps digital
Voice link for astronauts in station
Contamination requirements - to be determined

*An Instrument Pointing System (IPS) or the equivalent is assumed to deploy the SOT.

Supporting Instrumentation for Evolved ASO

The requirements shown next refer to the High Resolution Telescope Cluster exclusive of the Solar Terrestrial Observatory. The large field telescopes for observing global magnetic structure and activity, global flows, global oscillation, and solar irradiance will in general not present special problems of compatibility with the Space Station that will not have been addressed by integrating the major elements of ASO. High energy instrumentation is likely to include cryogenics; an on-board resupply capability for the cryogen may be a useful and cost-saving simplification.

Mass - 12,500 kg	Command rate - 10 kbps
Pointing accuracy - 1 arcsec	Power - 6.0 kW average, 8.5 kW peak
Pointing stability - 0.1 arcsec	Temperature range - 0 to 30 C
Data rate - 50 Mbps maximum with data compression	Interior volume 3m x 2m x 1m for operations console

Servicing Requirements

After initial placement and assembly of the major components, the evolutionary development of the ASO will require the capability to add new instruments and refurbish existing ones while they are in orbit. Expected activities include:

- Adding new instruments to the HRTC
- Replacing detectors
- Refurbishing optics
- Making repairs

Occasionally, an entire cluster may be returned to Earth for major repairs or refurbishment.

Data System Requirements

The end-to-end data system for the ASO must be carefully designed for maximum utility and ease of use by the solar astronomer. During an intense observational "campaign", the ASO will probably produce data at a higher rate than any previous astrophysical instrument. Some of the expected requirements are discussed below.

Telemetry Rates. A peak downlink rate of 50 to 100 Mbps is expected once ASO has both P/OF and SOT, with an average rate of about 10 Mbps. As new instruments are added, this rate could double. The uplink rates are expected to be much more modest, but as the ASO evolves, uplink may reach 1 Mbps for control purposes and microcomputer loads.

Interfacing New Instruments. The evolutionary development of the ASO will require adding new instruments. The data system must therefore be designed for expanding easily and economically.

Real-Time Monitoring and Control. For many areas of solar research, near-real-time data access is required to facilitate decisions on pointing and instrument modes. With nearly continuous TDRS coverage, most of the objectives can be accomplished with a ground based facility that can quickly process and display images from ASO and send commands based on decisions by a team of solar astronomers. This facility would also require access to data from ground-based observatories such as magnetograms and H-alpha images.

On-Board Control and Monitoring. The ASO should be capable of complete control from the ground, using Space Station systems only as a link between the instruments and the observers. However, it will also be useful and desirable to have monitoring equipment on board the Station and some degree of real time control. This will be especially needed if the Space Station telemetry system cannot continuously provide high data rates to the ground.

Data Distributions. The volume of scientific information from ASO presents a challenging problem for data distribution, processing and analysis. Fortunately, the early Shuttle flights of the SOT should provide an excellent test case for development of a cost effective plan. In addition to scientific data from the instruments, ancillary data from the Space Station (such as attitude and environment data) will also need to be distributed regularly.

Cosmic Ray Experiments

Generally speaking, the cosmic ray instruments (CRNE/TRIC, SCMF, HEIE, and the HESS Array) have low data rates and require low power. They measure isotropic fluxes and hence are not concerned with fine pointing. All except HESS Array require counter gas resupply. The Superconducting Magnet Facility requires cryogen resupply. The principle requirement associated with HESS Array is accommodation of its large mass.

CRNE/TRIC

The panel on the manned base concluded that accommodating CRNE/TRIC would present no difficulty for the Space Station. Although the instrument is quite complex, its complexity is entirely contained within its pressurized shell and the only requirements are for a clear view of space, in the direction away from Earth, over a large field of view. Specific requirements are the following:

Power - 500 W
Data rate - 50 to 100 kbps
Pointing direction - Zenith
Field of view - +/- 90 degrees
Aspect information - 5 degrees
Stability rate - <0.1 degree/sec
Total mass - 6,000 kg
Nominal altitude - 500 km (not critical)
Orbit inclination - 28 degrees (not critical)

SCMF

Because superconducting magnet technology has been used in cosmic ray studies for 15 years, its operational and safety considerations are well understood. In addition, a full scale prototype magnet was constructed as part of the early HEAO program.

Besides requirements for setting up SCMF, periodically reconfiguring the investigations, and resupplying the superconductor with liquid helium, there are operational requirements for a clear view of space in the direction pointing away from Earth with no part of the Space Station in the instrument's field of view. This condition need not be maintained rigorously; even a 50 percent duty cycle would be satisfactory.

Additional requirements include:

Size/Volume - Cylinder = two pallets in length, diameter fits in Shuttle bay

Electrical power (electronics) - 1,000 W	Data rate - 100 kbps
Pointing direction - Zenith	Field of view - +/- 45 degrees
Aspect information - 5 degrees	Stability rate - <0.1 degrees/sec
Total mass - 3,000 kg	Nominal orbit altitude - 500 km (not critical)
Orbit inclination - at least 28.5 degrees	

The extent of the stray magnetic field is quite small compared to the scale of Space Station. At a distance of 1 meter from the instrument, the magnetic field is less than 30 times the strength of the Earth's magnetic field, and the field dies off rapidly (with the sixth power of the distance). The magnet is designed with two coils of opposite polarity, so no net torque would be exerted on the Space Station. The magnet can be charged and discharged by the Space Station crew. The dewar would be designed with a lifetime between ½ and 2 years, and would require that its cryogen (liquid helium) be resupplied as needed.

HEIE

The Cosmic Ray Program Working Group recommended HEIE for early flight on a space platform. This is an isotope spectrometer with a large collecting area (1 square meter) and a mass resolution of better than 0.2 amu, with precisely stable operation over a 6-month flight. This experiment will be designed to fit within the pressure vessel of CRNE/TRIC, and its requirements will be very close to those of CRNE/TRIC. It could also be accommodated on a platform of the Explorer class or moderate mission class.

Power - 300 to 500 W	Aspect information - 5 degrees
Data rate - 30 to 100 kbps	Total mass - 2,500 to 5,000 kg
Pointing Direction - Zenith	Nominal altitude - 500 km (not critical)
Field of view - +/- 45 to +/- 90 degrees	Orbit inclination - 90 +/- 45 degrees

Stability rate - < 0.1 degree per second while the instrument is gathering data

Small Attached Payloads

In addition to the large solar and cosmic ray instruments described above, there exists another class of smaller payloads that are well-matched to the manned-base environment. Such payloads could be incorporated into the manned base with only a very modest impact on the overall configuration and resource allocations. A primary example of this class is gamma-ray burst studies. These experiments are generally modest in size, weight, telemetry, and power requirements. Zenith pointing is desirable, but inertial stabilization is acceptable. For a more detailed description of the scientific objectives and examples of instruments, the reader is referred to the section on the High Energy Transient Explorer in Volume 5, "Space Platforms for Astrophysics".

WORKSHOP ON

ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on

Space Station as a Manned Observation Base

Dr. J. David Bohlin, Chairman
Mr. Jack Barengoltz
Dr. Robert C. Golden
Dr. Hugh S. Hudson
Dr. Stuart D. Jordan
Dr. Joseph Klarman
Mr. James Marr
Mr. Edward Mettler
Dr. Ronald Moore
Mr. Robert G. Noblitt
Dr. Jonathan F. Ormes
Ms. Amelia Phillips
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